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REPORT

Heat risks in agriculture: Microclimate variability and worker safety in sweet corn and tobacco

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ABSTRACT
Agricultural work is one of the highest-risk U.S. occupations for heat-related illness (HRIs). Some tall-growing crops can block the cooling effects of wind or contribute to environmental humidity creating warm and humid microclimates (environments directly surrounding workers). The purpose of this study was to assess the differences in environmental heat stress within the center of tall-growing crop fields compared to the field perimeter. In the summer of 2023, two heat stress monitors collected daily measurements of wet bulb globe temperature (WBGT) in sweet corn and tobacco fields; results support that WBGT was higher at the field center of sweet corn and significantly higher at the field center of tobacco: 6.7% more hours in sweet corn and 13.6% more hours in tobacco were considered unsafe heat stress risk levels at the field center when compared to unsafe hours at the field perimeter. Unsafe heat stress risk levels were more likely to occur in the afternoons in the corn field while a high majority of all recorded hours in tobacco were considered unsafe, including the morning hours. The risk of laboring inside tall crop rows and heat-related illness should be considered in worker education and heat stress plans.

KEYWORDS
Agricultural workers; evapotranspiration; heat exposure; heat-related illnesses; wet-bulb globe temperature

Introduction

Agricultural work entails long work hours, physical exertion, and exposure to an array of biomechanical, physical, and chemical hazards, including direct sunlight, high temperatures, and humidity (Nguyen et al. 2018). Due to these and other factors, farmworkers are one of the highest risk groups for heat-related illness (HRI). Mortality from HRI among agricultural workers in the United States was nearly 35 times more likely compared to other workers (Gubernot et al. 2015). The majority of farmworkers in the U.S. (61%) are Latino migrants, and adverse effects, like HRIs, can be more likely due to concurrent factors they experience (Castillo et al. 2021; Fung et al. 2023). These concurrent factors could include, but are not limited to documentation status, fear of deportation, language/cultural barriers, and piecemeal pay (Castillo et al. 2021).

With increasing outdoor temperatures due to climate change (Ebi and Ziska 2018), accurate measures of workplace environmental exposures are needed to determine appropriate interventions to prevent HRI. Wet Bulb Globe Temperature (WBGT) serves as the preferred environmental heat metric for HRI prevention of all occupational groups (NIOSH 2016). WBGT measures dry air temperature, humidity, and radiant energy to calculate what thermal load a person is experiencing in direct sunlight, whereas heat index measures the thermal load in shaded areas (NIOSH 2016). Dally et al. (2020) observed the correlation of increasing WBGT to occupational injury; for every 1 °C increase in WBGT above 30 °C (86 °F), the mean count of daily recorded occupational injuries increased by 3%.

Crop fields uniquely contribute to environmental heat stress. Crops can transpire or lose water to the atmosphere from small openings on the leaf surfaces. Transpiration can increase humidity in the air, increasing the WBGT experienced by those working there (Souri et al. 2020). North Carolina farmworkers reported microclimates while laboring in tobacco fields, perceiving higher heat and humidity, which increased their thirst and need for water (Mizelle et al. 2022). Tall, dense crops may block the wind; thereby, increasing heat stress by inhibiting body cooling through sweat evaporation (NIOSH 2016;

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Osilla et al. 2023; Papadavid and Toulios 2018; State of California 2024).

While WBGT measurements have been collected in several farmworker HRI studies (Dally et al. 2020; Messeri et al. 2019; Mitchell et al. 2017; Vega-Arroyo et al. 2019; Wagoner et al. 2020), these studies were limited to one WBGT monitor or used data from local weather stations. Upon a literature review, no studies were found to have compared WBGT measurements from the middle of tall, dense crop fields to the field perimeter. Understanding more about the environments within crop rows that farmworkers are laboring in is an important step to effective prevention strategies and interventions against HRIs. The purpose of this study was to assess the heat stress exposure of workers within sweet corn and tobacco crops and to determine the differences of environmental heat stress within crop rows compared to the field perimeter.

Methods

This observational study compared the WBGT measurements and corresponding heat stress levels inside fields of sweet corn and tobacco to field perimeters. Data were collected using heat stress monitors in fields where farmworkers could have labored. The study did not involve human subjects or animals and, therefore, was approved by the East Carolina University Institutional Review Board (IRB) as exempt.

Monitoring sites

Crop fields in Bertie and Columbus counties, North Carolina (NC), were selected for data collection. These counties are in the warmest region of NC and consist of over 141,000 acres of farmland (National Agricultural Statistics Service 2022; National Centers for Environmental Information 2024). North Carolina has a large agricultural workforce (North Carolina Department of Health and Human Services 2024). The state has a disproportionately higher HRI fatality rate among farmworkers (Lambar and Thomas 2019; Luginbuhl et al. 2008), despite the average outdoor temperature being lower in NC than other top agricultural states such as Florida and Georgia (Diem et al. 2017). One explanation is that HRIs are strongly influenced by the difference between temperature extremes and the mean temperature (Patz et al. 2005).

Sweet corn and tobacco were selected due to the unique properties of the crops that could contribute to HRI. Sweet corn (*Zea mays*) and tobacco (*Nicotiana tabacum*) are tall crops, growing 5 to 8 and 3 to 5 ft (1.5 to 2.4 and 0.9 to 1.5 m), respectively (North Carolina State University 2023a, 2023b), which could promote wind block and increase humidity within the rows. Both crops require human judgment and manual labor for much of the maintenance and harvesting (Becerra-Sanchez and Taylor 2021; Diana et al. 2022). The labor is performed during the hottest months of the year and is often time-sensitive, requiring long hours of physical exertion under direct sunlight.

Heat stress monitoring

Two heat stress monitors were set up daily from 8 AM to 6 PM in an individual field. Measurements in the sweet corn field were collected in June, and tobacco collected in July and August 2023. These months were chosen because in North Carolina the manual labor required for sweet corn peaks in June and peaks in late summer for tobacco; therefore, the data would likely reflect the highest HRI-risk period in that specific crop due to peaks in farmworker presence in the field, as well as warm weather, urgency and physical labor as described above. In the corn field, one monitor was placed within a crop row approximately 200 ft (61 m) inside the field near the center. The other monitor was placed about 6 ft (1.8 m) from the corn field's perimeter. The fronts of the monitors were facing toward the east in Chadbourn, NC. While measuring in the tobacco field, one monitor was placed within a crop row, approximately 300 ft (91 m) inside the field, near the center. The fronts of the monitors were facing toward the northeast in Windsor, NC. The other monitor was also placed about 6 ft (1.8 m) from the tobacco field's perimeter. The tobacco and sweet corn crop rows were spaced 3 ft (0.9 m) apart.

The heat stress monitors used were two QUESTemp°34 (TSI Inc., Shoreview, MN). These heat stress monitors were used because in a comparison of 6 monitors, this model demonstrated the least amount of error (Cooper et al. 2017). Both monitors used in this study were calibrated by the manufacturer within one year. Both monitors were placed side-by-side on May 22, 2023, to assess for any discrepancies between measurements. The difference in the average WBGT from both monitors was 0.23 °C ($r = .993$, $n = 370$, $p < 0.01$).

In all the fields and monitor locations, heat stress monitors were set up on tripods, 3.5 feet (1.1 meters) above the ground (TSI Incorporated 2018). The monitor at the field perimeter was labeled Monitor 1 and the monitor at the field center was labeled Monitor 2.

The monitors logged the dry bulb, wet bulb, and globe temperatures, relative humidity, and heat index every minute, in degrees Celsius. Measurements of dry bulb temperature (no impact from other factors), wet-bulb temperature (represents sweat's effectiveness in cooling the body), and globe temperature (measures radiant energy from direct sunlight) were then used by the monitor to calculate the outdoor WBGT values (NIOSH 2016). Reflective bird deterrent tape was attached to a tripod nearby to prevent measurement interference. Data were downloaded from the monitors every four days to avoid substantial loss of data. Data were transferred to Excel documents, double checked for accuracy, and saved to a secure drive.

Following data collection, the hourly mean WBGT indices were calculated from the logged data. The hourly average of the measured WBGT was compared to the American Conference of Governmental Industrial Hygienists (ACGIH 2019) Threshold Limit Values (TLVs®). These TLVs provide recommendations on exposure limits regarding workload as well as the work/rest cycle. The field WBGT averages are analyzed and compared to the screening criteria WBGT to determine if they exceed recommended limits (ACGIH 2019; Danielle and Balanay 2020). Workload and work/rest cycle can increase the allowed TLV or decrease it based on longer/shorter breaks and increased/decreased activity. The farmworker's shift was considered 75% to 100% work/rest, and 15-minute breaks would be taken at 9 AM and 3 PM, with a 30 min break for lunch at 12 pm, as this was common for farmworkers in NC (Mizelle et al. 2022). The ACGIH® guidelines describe a moderate workload as "Sustained moderate hand and arm work, moderate arm and leg work, moderate arm, and trunk work, or light pushing/pulling and normal walking" (ACGIH 2019, 244). A moderate workload was determined appropriate for manual labor completed in tobacco and sweet corn (ACGIH 2019; Danielle and Balanay 2020). The ACGIH guidelines' heat stress risk levels for moderate workload are as follows; Minimal risk, WBGT less than 25 °C; Low risk, 25–25.7 °C; Moderate risk, 25.8–28.1 °C; High risk, 28.2–28.8 °C; Extreme risk, greater than 28.9 °C (2019). Anything considered to be "high" or "extreme" heat stress risk indicates that heat stress levels could be hazardous for all workers (Morris et al. 2019).

Data analyses

Independent-sample t-tests were used to compare the hourly averaged WBGT and humidity from the two monitors (SPSS Statistics for Windows 2021, v28). The WBGT and humidity averages were also broken down into Morning (0800–1059), Peak (1100–1359), and Afternoon (1400–1659) subsets and compared. To compare the differences between the assigned ACGIH TLVs and risk levels, hourly WBGT averages were calculated for each monitor. These values were then used to assign a risk level and determine if the hourly value given is over the TLVs. After this was completed, the percentage of total hours over the TLVs and the total number of risk levels were calculated for each monitor and differences were compared.

Results

Data were collected over 28 days for each crop, totaling 192 hr for tobacco and 225 hr for sweet corn. The results of paired sample t-tests are presented in Table 1 for corn and Table 2 for tobacco. These tests support that WBGT measurements were significantly higher within the crop row compared to the field perimeter for peak (11AM–2PM) and afternoon (2PM–5PM) times in tobacco. Figures 1 and 2 compare all WBGT measurements per monitor location and time of day for sweet corn and tobacco, respectively. The morning (8AM–11AM) and peak humidities in both tobacco and corn were also significantly higher at the field center. There was also a greater amount of unsafe risk levels and TLV exceedances within the crop row compared to the crop perimeter for most times in both crops.

Table 1. Paired sample WBGT and humidity results from corn.

	n	Field perimeter Mean (SD)	Field center Mean (SD)	*t*	*p*-value
WBGT (°C)					
Daily average	24	26.13 (2.52)	26.44 (2.84)	−0.407	.686
Morning	75	24.49 (2.93)	25.07 (3.57)	−1.089	.278
Peak	72	26.45 (2.63)	26.74 (3.00)	−0.608	.544
Afternoon	69	26.44 (2.36)	26.87 (2.63)	−1.010	.314
Humidity (%)					
	n	Field perimeter Mean (SD)	Field center Mean (SD)	*t*	*p*-value
Daily average	24	41.74 (9.08)	45.61 (9.90)	−1.412	.165
Morning	75	51.75 (15.06)	56.52 (13.80)	−2.022	.045*
Peak	72	40.32 (10.04)	45.51 (9.85)	−3.132	.002*
Afternoon	69	38.95 (12.06)	42.19 (11.98)	−1.582	.058

Morning 8 am to 10:59 am, Peak 11 am to 1:59 pm, Afternoon 2 pm to 4:59 pm.
*Significant, $p < 0.05$.

Assigned risk level categories and TLV exceedances in the center and perimeter of fields

For sweet corn, at the field perimeter, 16.9% of hours exceeded TLVs; while within the crop rows, 23.6% of hours exceeded TLVs. For tobacco, at the field perimeter, 73.4% of hours exceeded TLVs; while within the crop rows, 87.0% of hours exceeded TLVs. Table 3 compares the total risk level category percentages by monitoring location for both crops. Exceedance of TLVs in corn was more likely in the afternoon while a high majority of all recorded hours in tobacco exceeded TLVs, including morning hours. Table 4 shows total percentages that exceeded TLV and hourly TLV exceedances. At the noon hour, there was a notable decrease in TLV exceedance, which was reflective of the farmworker lunch break.

Table 2. Paired sample WBGT and humidity results from tobacco.

WBGT (°C)					
	n	Field perimeter Mean (SD)	Field center Mean (SD)	*t*	*p*-value
Daily average	14	30.21 (1.91)	31.22 (1.89)	−1.403	.172
Morning	24	28.34 (3.07)	28.75 (2.84)	−0.476	.637
Peak	75	30.46 (2.02)	31.77 (1.88)	−4.115	<.001*
Afternoon	54	30.30 (1.95)	31.84 (2.14)	−3.906	<.001*
Humidity (%)					
	n	Field perimeter Mean (SD)	Field center Mean (SD)	*t*	*p*-value
Daily average	14	40.22 (6.82)	45.67 (5.94)	−2.258	.033*
Morning	24	55.60 (18.19)	67.08 (15.09)	−2.381	.021*
Peak	75	40.81 (6.88)	43.32 (7.30)	−2.167	.032*
Afternoon	54	34.85 (7.97)	36.85 (8.54)	−1.258	.211

Morning 8 am to 10:59 am, Peak 11 am to 1:59 pm, Afternoon 2 pm to 4:59 pm.
*Significant, $p < 0.05$.

Discussion

This was the first study found to compare WBGT measurements from within the crop rows of crop fields to the field perimeter, in fields of tobacco and corn. The WBGT was higher within the crop rows of sweet corn and significantly higher at the field center of tobacco. With only a few degrees difference in WBGT, the microclimate within the crop rows made a notable difference in the risk levels for HRI. If farmworkers labored within the crop rows during this time and in these locations of NC, 6 to 14% more work hours were deemed unsafe.

Significant differences were found in relative humidity in the field centers of corn and tobacco. High humidity could inhibit physiological processes the body uses to cool, leading to an unsafe rise in core body temperature. Crop transpiration and evapotranspiration could explain the high relative humidity at the field center. The study findings align with the perceptions of North Carolina tobacco workers of

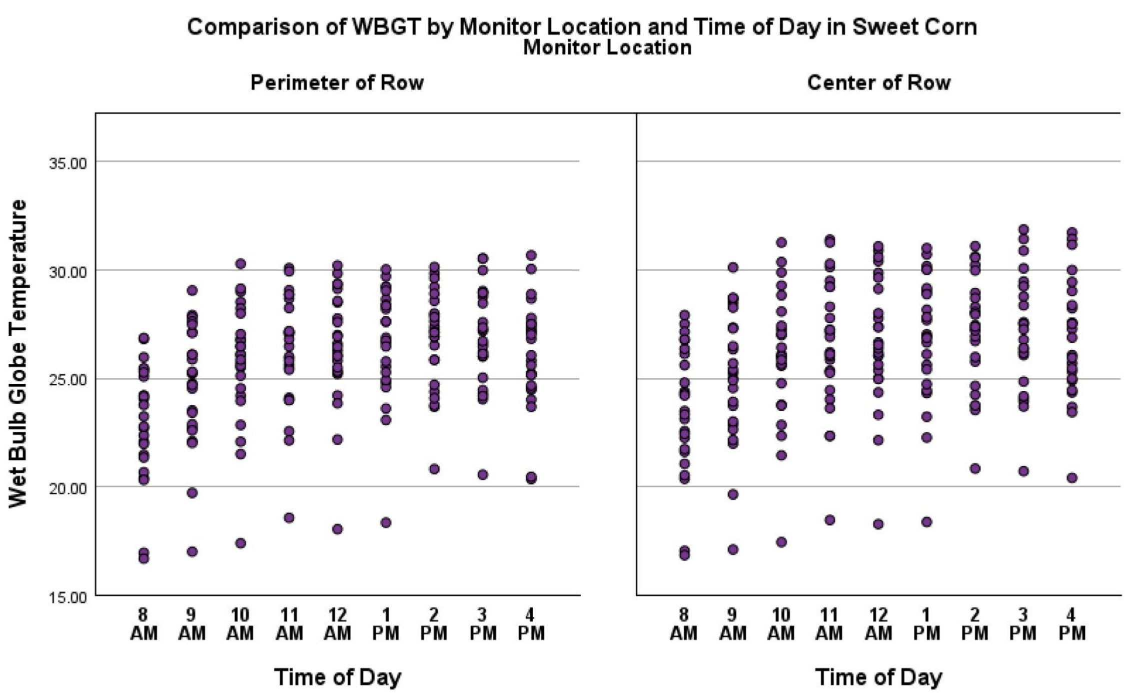

Figure 1. Comparison of WBGT by monitor location and time of day in sweet corn monitor location.

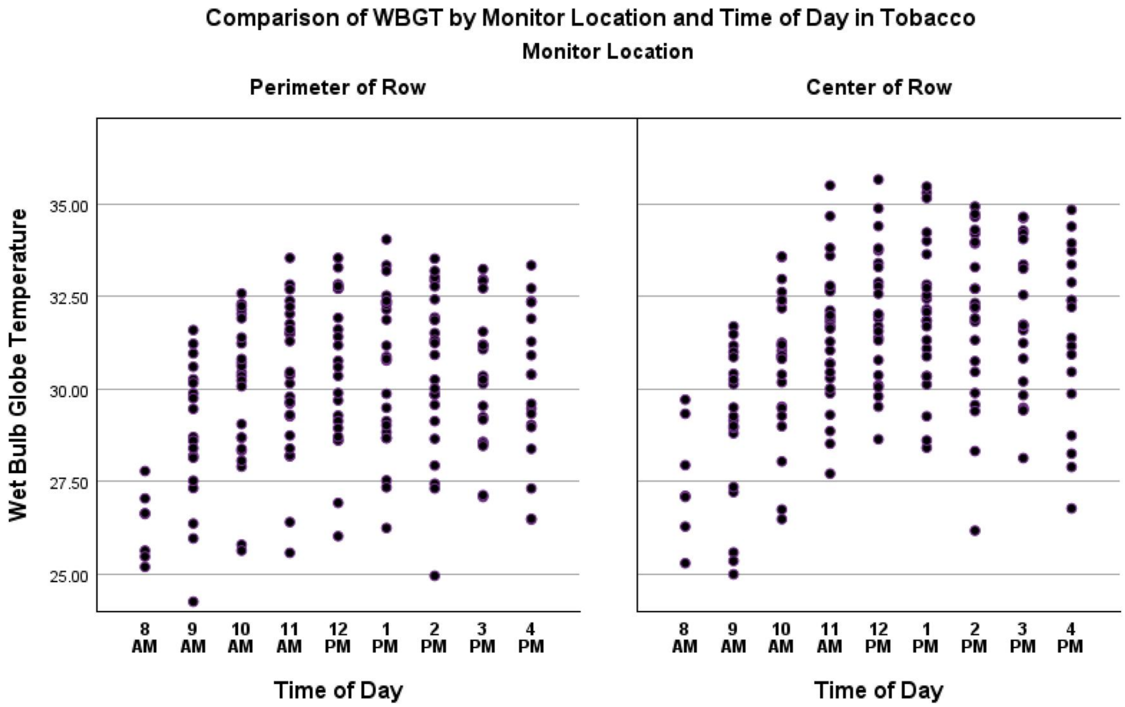

Figure 2. Comparison of WBGT by monitor location and time of day in tobacco monitor location.

Table 3. Risk level categories per monitor location and crop, percent of total hours.

	Sweet corn	
Risk level category	Perimeter of field	Field center
Minimal	32.00%	31.55%
Low	11.11%	8.44%
Moderate	36.00%	32.89%
High[a]	7.11%	7.11%
Extreme[a]	13.78%	20.00%
	Tobacco	
Risk level category	Perimeter of field	Field center
Minimal	2.08%	0.52%
Low	3.13%	2.08%
Moderate	13.02%	8.33%
High[a]	13.02%	4.17%
Extreme[a]	68.75%	84.90%

[a]Total heat stress that is hazardous for all workers (Morris et al. 2019).

Table 4. TLV exceedances per monitor location and crop, total, and hourly.

	Sweet corn	
Time of day	Perimeter of field	Field center
8 am	0.00%	0.00%
9 am	4.00%	4.00%
10 am	20%	28%
11 am	26.92%	30.77%
12 pm	4%	16%
1 pm	37.50%	37.50%
2 pm	23.08%	40.00%
3 pm	16.00%	28.00%
4 pm	20.00%	28.00 %
% exceeded for total hours	16.90%	23.60%
	Tobacco	
Time of day	Perimeter of field	Field center
8 am	0.00%	25.00%
9 am	45.00%	60.00%
10 am	84.00%	88.00%
11 am	92.31%	96.15%
12 pm	56.00%	88.00%
1 pm	88.00%	100.00%
2 pm	83.33%	95.83%
3 pm	76.00%	95.24%
4 pm	83.33%	88.89%
% exceeded for total hours	73.44%	86.98%

warmer and more humid microclimates within the crop rows (Mizelle et al. 2022).

Recently published was a similar study conducted in Washington State in 2022 (Flunker et al. 2024). These researchers also measured environmental heat stress indexes using QUESTemp°34 monitors in the center of crop rows and compared them to open field locations. Measuring among cherry trees about 14 ft (4.3 m) tall and among grape trellises 6 ft (1.8 m) tall, no significant difference in the WBGT was found within the crop rows *vs.* open locations. Flunker et al. was limited to three days of data collection. The authors reported that the cherry and grape crops had row spacing of around 9 feet (2.74 m). The tobacco and corn crop rows in this study were spaced much closer (3 ft/0.9 m) which could reduce airflow leading to higher WBGT readings (Vanderwende and Lundquist 2016).

Several farmworker health studies have collected or reported WBGT (Dally et al. 2020; Messeri et al. 2019; Mitchell et al. 2017; Vega-Arroyo et al. 2019; Wagoner et al. 2020), which is considered more accurate for assessing heat stress than outdoor temperature or heat index (NIOSH 2016). WBGT data were either measured using one monitor outside the crop field or from a local weather station, and most studies only collected data over a few days. Mitchell et al. (2017) and Vega-Arroyo et al. (2019) focused on low-lying crops such as squash, peppers, melons, etc., which are likely not tall enough to block wind. Dally et al. (2020) included WBGT measurements near sugarcane fields over several harvest seasons in Guatemala. Sugarcane grows 6 to 20 ft (1.8 to 6.1 m) tall. Although North Carolina has a subtropical climate and Guatemala is in the tropics, the average WBGT recorded in the Dally et al. (2020) study and the current study were almost identical, at 30 °C. While harvesting sugarcane occurs in the cooler months (November–April) and crops in North Carolina are harvested in the hottest months (June–September), crop harvesters in these areas could work in environments with similar HRI risk.

Personal monitors or sensors are an emerging technology. While most WBGT monitors are too large for individual use, there are a few handheld devices that can provide real-time measurement and reporting of WBGT (Carter et al. 2020). Individual heat and humidity sensors can be used to estimate WBGT and corresponding heat stress levels (Wang et al. 2019). Calculated WBGT from personal monitors clipped to worker shoes estimated 5.7% more work hours that exceeded ACGIH TLVs than data from the local weather stations, suggesting that using personal WBGT monitors may provide more accurate measurements than data from local weather stations. While many sensors on the market today are designed for athletes (Verdel et al. 2021), research is currently underway to develop sensors that are tailored to farm work (Kim et al. 2022).

While there are no occupational health and safety regulations that specifically address HRI prevention, five states currently have standards for occupational HRI protection. As of October 2021, OSHA initiated the rulemaking process to develop a federal heat-specific workplace standard; (Occupational Safety and Health Administration 2021) however, the current administration has issued a freeze on any rules from executive departments and agencies (U.S. Office of the Federal Register 2025). The federal standard would require employers to provide employees with HRI training, drinking water located close to the worksite, shaded rest breaks, and other HRI prevention interventions. As written in the Benefits section of the proposed law, OSHA projects compliance with this standard will substantially improve worker health and safety, "primarily through the reduction of occupational non-fatal heat-related injuries and illnesses (HRIs) and heat-related fatalities." The proposed standard emphasizes that currently, employers may not take adequate steps to protect workers from hazardous heat, such as not providing breaks. Passage of the proposed standard may help combat the current likelihood of inadequate protection.

Limitations

Overall, data collection was limited to one month for each crop and only over one agricultural season and therefore not generalizable to other crops or other locations. Farmworkers in NC commonly work 6 AM to 6 PM shifts, so data collection did not completely match their average daily exposure. Matched data were limited on some mornings, as data collection started at 9 AM instead of 8 AM. Rainy conditions, particularly in the afternoon, limited data collection on seven of the days. The monitors were fixed in place so may not represent farmworkers' true environmental exposures. The sweet corn data were likely not reflective of an average June in NC. The month of June 2023 was mild for NC, with an average temperature of 74.6 °F, ranking the lowest temperature for June in the past 10 years (National Centers for Environmental Information 2024). Because July is the hottest average month in NC, it was expected that the number of hours above the TLVs be greater in tobacco. The current study design makes it difficult to compare the two crops because WBGT measurements were not collected over the same period, but instead the data collection period likely reflected the highest risk periods for workers in these specific crops due to peak crop harvesting requirements.

Conclusions

Through several weeks of precise measurements of environmental heat metrics, this study supports that microclimates within crop fields could increase farmworker risk for HRI. This adds awareness of yet another health risk from farming and crop work. Farmworkers in North Carolina, particularly in tobacco crops, could spend the majority of their shifts working in environments deemed high or extremely high risk for HRI. Working in the morning hours could reflect lower WBGT and HRI risks. Workplace heat prevention plans should specify additional protections for work in dense, tall-growing crops.

Recommendations

Swift passage of the proposed OSHA heat standard could lead to improvements in worker health and safety. Legislators in states without occupational heat stress standards could pass temporary heat standards as the federal proposal could take several years to become regulation. Workplace heat prevention plans should specify additional protections while laboring in dense, tall-growing crops. Those additional protections could include fewer afternoon work hours inside the crop rows, longer or additional rest and water breaks, and wearing of loose-fitting clothing. Workplace heat stress monitoring to implement additional protections should be taken within the crop rows rather than outside of the crop rows. Further study of worker microclimate and worker heat strain could result in recommendations for additional rest time to accommodate the higher heat and humidity when working within the crop rows. Future microclimate studies could also provide more accurate HRI risk estimates by capturing breaks, movement, and changes in location. Education of employers and employees on WBGT readings should include reference ranges to emphasize that even small changes in the readout can denote substantial changes in HRI risk.

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Disclosure statement

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Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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